

CLAIM SET AS AMENDED

1. (Currently Amended) A semiconductor substrate comprising an insulating underlay and a crystalline silicon layer epitaxially grown thereon, said insulating underlay is ~~a semiconductor substrate~~ comprising a single crystal oxide substrate or a substrate comprising a silicon substrate and a crystalline oxide layer or fluoride layer stacked thereon,

wherein a defect density evaluated by a defect density measuring method of measuring number of pits per unit area formed by immersing in an iodine type etching solution is $7 \times 10^6/\text{cm}^2$ or less over the entire depth direction, and surface roughness of said crystalline silicon layer is 0.05nm to 2 nm ~~0.2 nm or less and 0.05 nm or more.~~

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2. (Original) The semiconductor substrate as claimed in Claim 1, wherein said crystalline silicon layer has a X-ray diffraction rocking curve full width at half maximum of a silicon (004) peak parallel to substrate surface is 0.24 degree to 0.03 degree, and X-ray diffraction rocking curve full width of a silicon (040) peak perpendicular to substrate surface is 0.18 degree or less and 0.03 degree.

3. (Original) The semiconductor substrate as claimed in Claim 1, wherein said crystalline silicon layer has a X-ray diffraction rocking curve full width at half maximum of a silicon

(040) peak perpendicular to substrate surface is smaller than X-ray diffraction rocking curve full width at half maximum of a silicon (004) peak parallel to substrate surface.

4. (Original) The semiconductor substrate as claimed in Claim 1, wherein said crystalline silicon layer has a X-ray diffraction rocking curve full width at half maximum of a silicon (040) peak perpendicular to substrate surface is almost constant over the entire depth direction and 0.18 degree to 0.03 degree.

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5. (Original) The semiconductor substrate as claimed in Claim 1, wherein, after part of said crystalline silicon layer is thermally oxidized to form a silicon oxide layer on said crystalline silicon layer, an interface level density measured by a charge pumping method is $3 \times 10^{11}/\text{cm}^2$ to $1 \times 10^9/\text{cm}^2$.

6. (Original) The semiconductor substrate as claimed in Claim 1, wherein thickness of said crystalline silicon layer is $0.03 \mu\text{m}$ to $0.7 \mu\text{m}$.

7. (Original) The semiconductor substrate as claimed in Claim 1, wherein said insulating underlay is said single crystal oxide substrate, and said single crystal oxide substrate is a sapphire substrate.

8. (Currently Amended) The semiconductor substrate as claimed in above Claim 1, wherein said insulating underlay is ~~said a laminated substrate, and wherein~~ said crystalline oxide layer stacked on silicon substrate ~~as said substrate~~ comprises one of α -Al₂O₃, γ -Al₂O₃, θ -Al₂O₃, MgO·Al₂O₃, CeO₂, SrTiO₃, (Zr_{1-x},Y_x)O_y, Pb(Zr, Ti)O₃, LiTaO₃, and LiNbO₃, and said fluoride layer comprises CaF₂.

9. (Original) A method of producing a semiconductor substrate with a low defect density silicon layer formed on an insulating underlay, said method comprising:

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(a) a step of forming a first silicon layer on said insulating underlay;

(b) a step of performing a first ion implantation to said first silicon layer to make deep part of interface amorphous, and recrystallizing said amorphous layer by a first heat treatment;

(c) a step of epitaxially growing a silicon layer on said first silicon layer to form a second silicon layer; and

(d) a step of performing a second ion implantation to said second silicon layer to make deep part of an interface amorphous, and recrystallizing said amorphous layer by a second heat treatment.

10. (Original) A method of producing a semiconductor substrate with a low defect density silicon layer formed on an insulating underlay, said method comprising:

(a) a step of forming a first silicon layer on said insulating underlay;

(b) a step of performing a first ion implantation to said first silicon layer to make deep part of interface amorphous, and recrystallizing said amorphous layer by a first heat treatment;

(c) a step of heat treating said recrystallized first silicon layer in an oxidizing atmosphere to oxidize part of surface side;

B3 (d) a step of removing silicon oxide film formed in said step (c) by etching;

(e) a step of epitaxially growing a silicon layer on remaining first silicon layer to form a second silicon layer; and

(f) a step of performing a second ion implantation to said second silicon layer to make deep part of interface amorphous, and recrystallizing said amorphous layer by a second heat treatment.

11. (Original) The method of producing a semiconductor substrate as claimed in Claim 10, wherein when said remaining first silicon layer is formed to a predetermined thickness, said steps (c) to (d) are repeated two times or more.

12. (Original) The method of producing a semiconductor substrate as claimed in Claim 10 or 11, wherein the silicon layer formed in said step (f) is regarded as said recrystallized first silicon layer formed in said step (b), and said steps (c) to (f) are repeated two times or more.

13. (Original) The method of producing a semiconductor substrate with a low defect density silicon layer formed on an insulating underlay, said method comprising:

(a) a step of forming a first silicon layer on said insulating underlay;

B3 (b) a step of heat treating said first silicon layer in an oxidizing atmosphere to oxidize part of surface side;

(c) a step of removing silicon oxide film formed in said step (b) by etching;

(d) a step of epitaxially growing a silicon layer on remaining first silicon layer to form a second silicon layer; and

(e) a step of ion implanting to said second silicon layer to make a deep part of interface amorphous, and recrystallizing said amorphous layer by heat treatment.

14. (Original) The method of producing a semiconductor substrate as claimed in Claim 13, wherein when said remaining first silicon layer is formed to a predetermined thickness, said steps (b) to (c) are repeated two times or more.

15. (Original) The method of producing a semiconductor substrate as claimed in Claim 13, wherein said silicon layer formed in said step (e) is regarded as said first silicon layer formed in said step (a), and said steps (b) to (e) are repeated two times or more.

16. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 10, wherein said oxidizing atmosphere contains a mixed gas of oxygen and hydrogen or water vapor.

B3 17. (Currently Amended) The production method of semiconductor substrate as claimed in Claim 10, wherein temperature of heat treatment in said oxidizing atmosphere is 600°C to or more and 1300°C or less.

18. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 10, wherein heat treatment in said oxidizing atmosphere comprises two-stage heat treatment of different temperatures of a high temperature heat treatment performed at a high temperature and a low temperature heat treatment performed at a lower temperature subsequent to said high temperature heat treatment.

19. (Original) The method of producing a semiconductor substrate as claimed in Claim 18, wherein the temperature of the high temperature heat treatment in said oxidizing atmosphere is 800°C to 1200°C and the temperature of the low temperature heat treatment in said oxidizing atmosphere is 700°C to 1100°C.

20. (Currently Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein temperature at which a silicon layer is epitaxially grown on said first silicon layer to form a second silicon layer is 550°C to ~~or more and 1050°C or less.~~

21. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein before said step of epitaxially growing a silicon layer on said first silicon layer to form a second silicon layer, said first silicon layer is heat treated in a hydrogen atmosphere or in vacuum.

22. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein a base pressure of growing chamber of apparatus used when a silicon layer is epitaxially grown on said first silicon layer to form a second silicon layer is 10^{-7} Torr or less.

23. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein method of epitaxially growing a silicon layer on said first silicon layer to form a second silicon layer is a UHV-CVD method or a MBE method.

24. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein when epitaxially growing a silicon layer on said first silicon layer to form a second silicon layer, growing temperature is set high only in an initial stage of growth.

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25. (Original) The method of producing a semiconductor substrate as claimed in Claim 24, wherein method of epitaxially growing a silicon layer on said first silicon layer to form a second silicon layer is an APCVD method or a LPCVD method.

26. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein after said step of ion implanting to said second silicon layer to make deep part of interface amorphous, and recrystallizing said amorphous layer by heat treatment, or after said step of epitaxially growing a silicon layer to form a second silicon layer, further comprising a step of heat treatment in hydrogen.

27. (Original) The method of producing a semiconductor substrate as claimed in Claim 26, wherein temperature of said heat treatment in hydrogen is 800°C to 1200°C.

28. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein after said step of ion implanting to said second silicon layer to make deep part of interface amorphous, and recrystallizing said amorphous layer by heat treatment, surface of silicon layer is flattened.

133 29. (Original) The method of producing a semiconductor substrate as claimed in Claim 28, wherein said method of flattening surface of said silicon layer is a chemical and/or mechanical polishing.

30. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein said step of forming a first silicon layer on said insulating underlay is a step of epitaxially growing said first silicon layer on said insulating underlay.

31. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein said insulating underlay is a single crystal oxide substrate.

32. (Original) The method of producing a semiconductor substrate as claimed in Claim 31, wherein said insulating underlay is a sapphire substrate.

33. (Previously Amended) The production method of semiconductor substrate as claimed in Claim 9, wherein said insulating underlay is a laminated substrate comprising crystalline oxide layer or fluoride layer stacked on a silicon substrate as a substrate.

B3 34. (Original) The method of producing a semiconductor substrate as claimed in Claim 33, wherein said crystalline oxide layer comprises one of α -Al₂O₃, γ -Al₂O₃, θ -Al₂O₃, MgO.Al₂O₃, CeO₂, SrTiO₃, (Zr_{1-x},Y_x)O_y, Pb(Zr, Ti)O₃, LiTaO₃, and LiNbO₃, and said crystalline fluoride layer comprises CaF₂.

35. (Previously Amended) The semiconductor substrate characterized in that it is produced by the production method as claimed in Claim 9.

36. (Currently Amended) The ~~A~~ semiconductor substrate as ~~claimed in Claim 1, characterized by comprising an insulating underlay and a crystalline silicon layer epitaxially grown~~

~~thereon, said insulating underlay comprising a single crystal oxide substrate or a substrate comprising a silicon substrate and a crystalline oxide layer or fluoride layer stacked thereon,~~

~~wherein a defect density evaluated by a defect density measuring method of measuring number of pits per unit area formed by immersing in an iodine type etching solution is $7 \times 10^6/\text{cm}^2$ or less over the entire depth direction, and surface roughness of said crystalline silicon layer is 0.05nm to 0.2 nm;~~

~~wherein said semiconductor substrate is characterized in that it is produced by the production method as claimed in Claim 9.~~

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37. (Currently Amended) A semiconductor device characterized in that ~~it is a semiconductor device using a semiconductor substrate as substrate, as said semiconductor substrate, comprising the semiconductor substrate as claimed in Claim 1 is used, whereby improving for improved device characteristics.~~

38. (Currently Amended) The semiconductor device as claimed in Claim 37, wherein said semiconductor device is MOSFET, and said ~~improved device characteristic improved by using the semiconductor substrate as claimed in Claims 1 as semiconductor substrate thereof is at least one of mutual conductance, cut-off~~

frequency, flicker noise, electrostatic discharge, drain withstand voltage, dielectric breakdown charge amount, and leakage current characteristics.

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39. (Currently Amended) The semiconductor device as claimed in Claim 38, wherein said ~~MOSFET uses the semiconductor substrate as claimed in Claim 1 as the semiconductor substrate thereof, is a MOSFET formed on a semiconductor substrate with~~ has a thickness of crystalline silicon layer of $0.03\mu\text{m}$ ~~or more and to~~ $0.7\mu\text{m}$ or less, no kink appears in current-voltage characteristic, drain withstand voltage for the case of a gate length of $0.8\mu\text{m}$ is 7V or more, and has a characteristic that input gate voltage spectral density representing flicker noise is $3 \times 10^{-12} \text{ V}^2/\text{Hz}$ or less at a measuring frequency of 100 Hz.

40. (Currently Amended) The semiconductor device as claimed in Claim 37, wherein said semiconductor device is a bipolar transistor, and device characteristic improved by ~~using the semiconductor substrate as claimed in Claim 1 as semiconductor substrate thereof~~ is at least one of mutual conductance, cut-off frequency, collector current, leakage current, and current gain.

41. (Currently Amended) The semiconductor device as claimed in Claim 37, wherein said semiconductor device is a diode, and

device characteristic improved by ~~using the semiconductor substrate as claimed in Claim 1 as semiconductor substrate~~ thereof is at least one of reverse bias leakage current, forward bias current, and diode factor.

42. (Currently Amended) The semiconductor device as claimed in Claim 41, wherein said diode is a pin photodiode formed on the semiconductor substrate, ~~as claimed in Claim 1 as~~ wherein the semiconductor substrate thereof ~~having~~ has a thickness of crystalline silicon layer of $0.03\mu\text{m}$ ~~or more and to~~ $0.7\mu\text{m}$ or less, having a pin area width of each $1\mu\text{m}$, and having characteristics that dark current measured under a condition applied with a 2V reverse bias is 10^{-11} A or less, and photocurrent under light irradiation of $1\text{W}/\text{cm}^2$ intensity at wavelength 850 nm is 10^{-10} A or more.

43. (Currently Amended) The semiconductor device as claimed in Claim 37, wherein said semiconductor device is a semiconductor device integrated circuit, and device characteristic improved by ~~using the semiconductor substrate as claimed in Claim 1 as semiconductor substrate~~ thereof is at least one of frequency characteristic, noise characteristic, amplification characteristic, and power consumption characteristic.

44. (Previously Amended) A semiconductor device using a semiconductor substrate as a substrate characterized in that as said semiconductor substrate, the semiconductor substrate produced by the production method as claimed in Claim 9 is used, whereby improving device characteristics.

B3 45. (Original) The semiconductor device as claimed in Claim 44, wherein said semiconductor device is a MOSFET, and said device characteristic is at least one of trans-conductance, cut-off frequency, flicker noise, electrostatic discharge, drain breakdown voltage, dielectric breakdown charge amount, and leakage current characteristics.

46. (Original) The semiconductor device as claimed in Claim 45, wherein said MOSFET is formed on the semiconductor substrate with a thickness of crystalline silicon layer of $0.03\mu\text{m}$ to $0.7\mu\text{m}$, and no kink appears in a current - voltage measurement, a drain breakdown voltage as a measured using a gate length of $0.8\mu\text{m}$ is 7V or more, and an input gate voltage spectral density representing flicker noise is $3 \times 10^{-12} \text{ V}^2/\text{Hz}$ or less at a measuring frequency of 100 Hz.

47. (Original) The semiconductor device as claimed in Claim 44, wherein said semiconductor device is a bipolar transistor,

and said device characteristic is at least one of trans-conductance, cut-off frequency, collector current, leakage current, and current gain.

48. (Original) The semiconductor device as claimed in Claim 44, wherein said semiconductor device is a diode, and said device characteristic is at least one of reverse bias leakage current, forward bias current, and diode factor.

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49. (Currently Amended) The semiconductor device as claimed in Claim 48, wherein said diode is a pin photodiode formed on the semiconductor substrate ~~as claimed in Claim 1 as said and the~~ semiconductor substrate ~~thereof having~~ has a thickness of crystalline silicon layer of $0.03\mu\text{m}$ ~~or more and~~ $0.7\mu\text{m}$ ~~or less~~, having a pin area width of each $1\mu\text{m}$, and having characteristics that dark current measured under a condition applied with a 2V reverse bias is 10^{-11} A or less, and photocurrent under light irradiation of $1\text{W}/\text{cm}^2$ intensity at wavelength 850 nm is 10^{-10} A or more.

50. (Original) The semiconductor device as claimed in Claim 44, wherein said semiconductor device is a semiconductor integrated circuit, and said device characteristic is at least one of frequency characteristic, noise characteristic,

amplification characteristic, and power consumption characteristic.

51. (Original) A method of producing a semiconductor device comprising an insulating underlay and a silicon layer formed thereon, said production method comprising:

(a) a step of forming a first silicon layer on said insulating underlay;

(b) a step of performing a first ion implantation to said first silicon layer to make a deep part of an interface amorphous, and recrystallizing said amorphous layer by a first heat treatment;

(c) a step of epitaxially growing a silicon layer on said first silicon layer to form a second silicon layer;

(d) a step of performing a second ion implantation to said second silicon layer to make a deep part of an interface amorphous, and recrystallizing said amorphous layer by a second heat treatment; and

(e) after heat treating said silicon layer formed in said step (d) in an oxidizing atmosphere to oxidize part of surface side, a step of removing said formed silicon oxide film by etching to adjust said silicon layer to a desired thickness.

52. (Original) A method of producing a semiconductor device comprising an insulating underlay and a silicon layer formed

thereon, said method comprising:

(a) a step of forming a first silicon layer on said insulating underlay;

(b) a step of performing a first ion implantation to said first silicon layer to make a deep part of an interface amorphous, and recrystallizing said amorphous layer by a first heat treatment;

(c) a step of heat treating said recrystallized first silicon layer in an oxidizing atmosphere to oxidize part of surface side;

(d) a step of removing said silicon oxide film formed in said step (c) by etching;

B3 (e) a step of epitaxially growing a silicon layer on remaining first silicon layer to form a second silicon layer;

(f) a step of performing a second ion implantation to said second silicon layer to make a deep part of an interface amorphous, and recrystallizing said amorphous layer by a second heat treatment;

(g) after heat treating said silicon layer formed in said step (f) in an oxidizing atmosphere to oxidize part of surface side, a step of removing said formed silicon oxide film by etching to adjust said silicon layer to a desired thickness.

53. (Original) The method of producing a semiconductor device as claimed in Claim 52, wherein when forming said

remaining first silicon layer to a predetermined thickness, said steps (c) to (d) are repeated two times or more.

54. (Original) The method of producing a semiconductor device as claimed in any one of Claims 52 to 53, wherein said silicon layer formed in said step (f) is regarded as said recrystallized first silicon layer formed in said step (b), and said steps (c) to (f) are repeated two times or more.

55. (Original) A method of producing a semiconductor device comprising an insulating underlay and a silicon layer formed thereon, said method comprising:

133 (a) a step of forming a first silicon layer on said insulating underlay;

(b) a step of heat treating said first silicon layer in an oxidizing atmosphere to oxidize part of surface side;

(c) a step of removing said silicon oxide film formed in said step (b) by etching;

(d) a step of epitaxially growing a silicon layer on said remaining first silicon layer to form a second silicon layer;

(e) a step of ion implanting to said second silicon layer to make a deep part of an interface amorphous, and recrystallizing said amorphous layer by heat treatment; and

(f) after heat treating said silicon layer formed in said step (e) in an oxidizing atmosphere to oxidize part of surface

side, a step of removing said formed silicon oxide film by etching to adjust said silicon layer to a desired thickness.

56. (Original) The method of producing a semiconductor device as claimed in Claim 55, wherein when forming said remaining first silicon layer to a predetermined thickness, said steps (b) to (c) are repeated two times or more.

57. (Original) The method of producing a semiconductor device as claimed in any one of Claims 55 to 56, wherein said silicon layer formed in said step (e) is regarded as said first silicon layer formed in said step (a), and said steps (b) to (e) are repeated two times or more.

58. (Previously Amended) The production method of semiconductor device as claimed in Claim 51, wherein after said step of ion implanting to said second silicon layer to make deep part of interface amorphous and recrystallizing said amorphous layer by heat treatment, or after said step of epitaxially growing said silicon layer to form a second silicon layer, further comprising a step of heat treatment in hydrogen.

59. (Previously Amended) The production method of semiconductor device as claimed in Claim 51, wherein after said step of ion implanting to said second silicon layer to make deep

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B3 part of interface amorphous and recrystallizing said amorphous layer by heat treatment, surface of said silicon layer is flattened by chemical and/or mechanical polishing.
